



MICRO-ACTUATOR ARRAY, MICRO-ACTUATOR DEVICE, OPTICAL SWITCH,
AND OPTICAL SWITCH SYSTEM

INCORPORATION BY REFERENCE

5 The disclosures of the following priority application
are herein incorporated by reference:

Japanese Patent Application No. 2002-349313 filed
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10 BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a micro-actuator array, and a micro-actuator device, an optical switch array, and an optical switch system, which use the micro-actuator array.

15 Such an optical switch array may be used in, for example, optical communication.

2. Description of the Related Art

Development in micromachining technology has increased
20 the importance of actuators in various fields. A
microactuator may be used in, for example, the field of an
optical switch used in, for example, optical communication
and used for switching optical paths. An example of such an
optical switch is disclosed in, for example, Japanese
25 Unexamined Patent Application Publication No. 2001-42233.

A microactuator for moving a micromirror is used in the optical switch disclosed in Japanese Unexamined Patent Application Publication No. 2001-42233. The microactuator comprises a movable section which is movable with respect to a fixed section. The movable section can be restored to an upper position (where the micromirror reflects incident light) by its springiness. A first electrode (fixed electrode) is disposed at the fixed section, and a second electrode (movable electrode) is disposed at the movable section. By applying a voltage between the first and second electrodes to generate an electrostatic force therebetween, the movable section is moved to a lower position (where the micromirror transmits incident light as it is) and held there. When the application of the voltage between the first and second electrodes is stopped, the movable section is restored to the upper position by its springiness.

Another example of an optical switch is a matrix optical switch disclosed in Japanese Unexamined Patent Application Publication No. 5-113543. In the optical switch, very small mirrors are driven by a plurality of microactuators disposed in a matrix on the same substrate. The driving principle of each microactuator is, for example, electromagnetic induction. In addition, in the optical switch, for example, a selective circuit and address circuits (X address decoder and Y address decoder) for

supplying a drive signal to each microactuator by decoding a command signal are disposed on the substrate.

Optical switches are available in various sizes, from small sizes of 2×2 channels and 4×4 channels to large 5 sizes of 128×128 channels and 256×256 channels.

Japanese Unexamined Patent Application Publication No. 2001-42233 only discloses a one-channel optical switch. As in Japanese Unexamined Patent Application Publication No. 5-113543, the size of this optical switch can be increased by 10 disposing a plurality of the microactuators disclosed in Japanese Unexamined Patent Application Publication No. 2001-42233 on the same substrate.

When an optical switch is formed by disposing a plurality of microactuators using electrostatic force, the 15 wiring method differs depending upon the size of the optical switch.

Although not disclosed in Japanese Unexamined Patent Application Publication No. 2001-42233 or Japanese Unexamined Patent Application Publication No. 5-113543, in a 20 small optical switch, conventionally, either one of the fixed electrodes and the movable electrodes of the respective microactuators are electrically connected in common on a substrate and are defined as common electrodes, whereas the other of the fixed electrodes and movable 25 electrodes of the respective microactuators are used as

individual electrodes without being electrically connected to each other. These electrodes are connected outside the substrate. Therefore, for example, for an $N \times N$ channel optical switch, $N^2 + 1$ wires are connected outside the 5 substrate. The phrase " electrodes are connected outside the substrate" refers to electrically connecting an external connection wiring to the electrodes. For convenience of explanation, the aforementioned method will be called a "common electrode/individual electrode external connection 10 method."

In contrast, in a large optical switch, conventionally, as disclosed in Japanese Unexamined Patent Application Publication No. 5-113543, for example, an address circuit and a selective circuit are formed using, for example, CMOS 15 on a substrate on which the microactuators are mounted, and about ten wires are connected outside the substrate. For convenience of explanation, such a method will be called an address circuit mounting method.

The address circuit mounting method is very 20 advantageous from the viewpoint that a small number of wires are connected outside the substrate even if the optical switch is large. However, the address circuit mounting method has the following first to third disadvantages. Therefore, if the optical switch is not at least a certain 25 size, the disadvantages far outweigh the advantages. As a

result, the address circuit mounting method is not suitable for optical switches of intermediate and smaller sizes.

The first disadvantage of the address circuit mounting method is that highly pressure-resistant MOS is required for 5 forming, for example, an address circuit and a selective circuit because a voltage of about tens of volts, or in some cases a high voltage equal to or greater than 100 volts, is often required for electrostatically driving an actuator.

Since a device formed of a highly pressure-resistant MOS has 10 a larger planar size than that formed of an ordinary MOS, the size of the actuator is also increased. The second disadvantage is that costs are increased because the number of steps of a production process is increased by a MOS production step. The third disadvantage is that costs are 15 increased due to the addition of a smoothening step, which is carried out because, if smoothening is not sufficiently carried out after producing MOS, the shape of a base is transferred to the shape of MEMS (Micro Electro Mechanical System) to be formed on top of MOS, causing malfunctioning.

20 In contrast to this, the common electrode/individual electrode external connection method does not have the disadvantages of the address circuit mounting method because an address circuit, a selective circuit, etc., are not mounted. However, even if the optical switch is of an 25 intermediate or smaller size, the optical switch becomes

only slightly larger, with the number of wires to be externally connected being considerably increased. Therefore, the optical switch can be formed with a size of the order of 8×8 channels at most. Even if the optical 5 switch is an 8×8 channel optical switch, it is necessary to externally connect as many as 65 wires.

SUMMARY OF THE INVENTION

10 The present invention provides a microactuator array which makes it possible to reduce the number of wires which are externally connected, and a microactuator device, an optical switch array, and an optical switch system, which use the microactuator array.

15 A first microactuator array of the present invention comprises:

a plurality of first terminals equal in number to a first number;

20 a plurality of second terminals equal in number to a second number; and

a plurality of microactuators equal in number to the product of the first number and the second number,

25 wherein each microactuator comprises a fixed electrode and a movable electrode which is movable with respect to the fixed electrode by electrostatic force,

wherein each first terminal is electrically connected to fixed electrodes of microactuators equal in number to the second number,

5 wherein each second terminal is electrically connected to movable electrodes of microactuators equal in number to the first number, and

 wherein the first terminals are not connect to any of the second terminals.

In the microactuator array, it is desirable that the
10 microactuators equal in number to the product of the first number and the second number be disposed in a lattice in a two-dimensional plane; one end of each microactuator be fixed at the fixed electrode, and the other end of each microactuator be moved with respect to the fixed electrode
15 and have a beam section where the movable electrode is disposed; and each beam section be two-dimensionally bent and a portion of each beam section be two-dimensionally superimposed on the beam section of an adjacent microactuator.

20 It is desirable that mirrors for switching optical paths be provided, each mirror being disposed at a movable section including the corresponding movable electrode of the corresponding microactuator.

A first microactuator device of the present invention
25 comprises the microactuator array, and a controller for

selectively applying a voltage to the first terminals equal in number to the first number and the second terminals equal in number to the second number.

In the microactuator device, it is desirable that, when
5 the movable electrode of a first microactuator is driven so as to be attracted to the fixed electrode, the controller applies a voltage to a second terminal connected to the movable electrode of the first microactuator and to a first terminal connected to the fixed electrode of the first
10 microactuator so that a potential difference between the movable electrode and the fixed electrode of the first microactuator is equal to or greater than a predetermined potential difference.

It is desirable that the microactuator device further
15 comprise:

a magnetic field generating section for generating a magnetic field around the microactuator array,

wherein each microactuator has an electrical current path, disposed at a movable section including the
20 corresponding movable electrode, for generating Lorentz force in the magnetic field, and

wherein, when the movable electrode of a first microactuator is driven so as to be attracted to the fixed electrode, the controller applies a predetermined voltage to
25 the second terminal connected to the movable electrode of

the first microactuator and to the first terminal connected to the fixed electrode of the first microactuator, and passes a predetermined electrical current through an electrical current path of the first microactuator.

5 A second microactuator array of the present invention comprises a plurality of microactuators; a first terminal group comprising a plurality of terminals; and a second terminal group comprising a plurality of terminals, wherein
(a) each microactuator comprises a movable section disposed
10 so as to be movable with respect to a fixed section, a first electrode disposed at the fixed section, and a second electrode disposed at the movable section and capable of generating electrostatic force between the first electrode and the second electrode by a voltage applied between the
15 first electrode and the second electrode, (b) the movable section of each microactuator is disposed so as to be movable between a first position where the electrostatic force is increased and a second position where the electrostatic force is reduced or eliminated, and so that a
20 restoring force for restoring the movable section of each microactuator to the second position is generated, (c) the first electrode of each microactuator is electrically connected to one terminal of either one of the first terminal group and the second terminal group, and is not
25 electrically connected to the rest of the terminals of the

first and second terminal groups, (d) the second electrode of each microactuator is electrically connected to one terminal of the other of the first terminal group and the second terminal group, and is not electrically connected to the rest of the terminals of the first and second terminal groups, (e) a combination of the one terminal of either one of the first terminal group and the second terminal group electrically connected to the first electrode of each microactuator and the one terminal of the other of the first terminal group and the second terminal group electrically connected to the second electrode of each microactuator is characteristic of each microactuator, (f) at least one terminal of the first terminal group is electrically connected to the first electrodes or the second electrodes of at least two of the plurality of microactuators, and (g) at least one terminal of the second terminal group is electrically connected to the first electrodes or the second electrodes of at least two of the plurality of microactuators. The movable section is formed of, for example, a thin film.

The term "characteristic" in (e) above means that, when any one terminal is selected from the first terminal group and any one terminal is selected from the second terminal group, there is only one microactuator corresponding to these two terminals (that is, there is only one actuator in

which the two terminals are electrically connected to the two electrodes, respectively).

In the microactuator array, it is desirable that (a) when m and n are integers equal to or greater than 2, the 5 number of the plurality of microactuators be $m \times n$ actuators, (b) the number of terminals of the first terminal group be equal to m , (c) the number of terminals of the second terminal group be equal to n , (d) each terminal of the first terminal group be electrically connected to the first 10 electrodes or the second electrodes of n microactuators of the plurality of microactuators, and (e) each terminal of the second terminal group be electrically connected to the first electrodes or the second electrodes of m microactuators of the plurality of microactuators.

15 The expression " $m \times n$ " simply represents the number of the plurality of microactuators, so that the arrangement of the microactuators is not necessarily limited to a matrix arrangement of m rows $\times n$ columns.

A second microactuator device of the present invention 20 comprises the second microactuator, and a controlling section which is connected to the terminals of the first and second terminal groups, and which controls switching between the positions of the movable sections of the respective microactuators by controlling electrical potentials at the 25 respective terminals of the first and second terminal groups.

In the microactuator device, it is desirable that (a) the controlling section is constructed so that each terminal of the first terminal group is settable at first, second, and third electrical potential states, and so that each 5 terminal of the second terminal group is settable at fourth, fifth, and sixth electrical potential states, (b) the magnitudes of electrical potentials of the first to sixth electrical potential states satisfy a relationship: the electrical potential of the first electrical potential state 10 > the electrical potential of the second electrical potential state > the electrical potential of the third electrical potential state \geq the electrical potential of the fourth electrical potential state > the electrical potential of the fifth electrical potential state > the electrical potential of the sixth electrical potential state, or 15 satisfy the reverse relationship in magnitude, (c) the difference between the electrical potential of the first electrical potential state and the electrical potential of the sixth electrical potential state be a voltage which moves to the first position the movable section of at least 20 one microactuator, among the plurality of microactuators, having the movable section positioned at the second position when the electrical potential difference is applied between the first and second electrodes of the at least one 25 microactuator, (d) the difference between the electrical

potential of the third electrical potential state and the electrical potential of the fourth electrical potential state be a voltage which restores to the second position the movable section of at least one microactuator, among the 5 plurality of microactuators, having the movable section positioned at the first position when the electrical potential difference is applied between the first and second electrodes of the at least one microactuator, (e) the difference between the electrical potential of the third 10 electrical potential state and the electrical potential of the fifth electrical potential state and the difference between the electrical potential of the second electrical potential state and the electrical potential of the fourth electrical potential state be voltages which maintain at the 15 first position and do not restore to the second position the movable section of at least one microactuator, among the plurality of microactuators, having the movable section positioned at the first position when the electrical potential differences are applied between the first and 20 second electrodes of the at least one microactuator, and (f) the difference between the electrical potential of the second electrical potential state and the electrical potential of the fifth electrical potential state be a voltage which maintains at the second position and does not 25 restore to the first position the movable section of at

least one microactuator, among the plurality of microactuators, having the movable section positioned at the second position when the electrical potential difference is applied between the first and second electrodes of the at 5 least one microactuator.

Each electrical potential state may be, for example, a state in which the electrical potential does not change with time, a state in which the electrical potential changes in the form of pulses with time, or a state in which the 10 electrical potential sinusoidally changes with time.

In this case, it is desirable that the first electrical potential state and the third electrical potential state be the same.

In the second microactuator array, it is desirable that 15 the movable section of each microactuator have an electrical current path for generating Lorentz force by disposing the electrical path of each microactuator in a magnetic field and passing electrical current.

A third microactuator device of the present invention 20 comprises a microactuator array in which an electrical current path which generates Lorentz force by placing the electrical current path in a magnetic field and passing electrical current is disposed at the movable section of each of the above-described microactuators, a magnetic field 25 generating section for generating the magnetic field, and a

controlling section which is electrically connected to each terminal of the first and second terminal groups and the electrical current path of each microactuator array, and which controls switching between the positions of the 5 movable section of each microactuator by controlling an electrical potential of each terminal of the first and second terminal group and the electrical current flowing in the electrical current path of each microactuator array.

In the microactuator device, it is desirable that (a) 10 the controlling section be constructed so that each terminal of the first terminal group is settable at first and second electrical potential states and so that each terminal of the second terminal group is settable at third and fourth electrical potential states, (b) the difference between an 15 electrical potential of the second electrical potential state and an electrical potential of the fourth electrical potential state be a voltage which moves to the first position the movable section of at least one microactuator, among the plurality of microactuators, having the movable 20 section positioned at the second position when the electrical potential difference is applied between the first and second electrodes of the at least one microactuator and when a predetermined electrical current is passed through the electrical current path of the at least one 25 microactuator, (c) the difference between an electrical

potential of the first electrical potential state and an electrical potential of a third electrical potential state be a voltage which restores to the second position the movable section of at least one microactuator, among the 5 plurality of microactuators, having the movable section positioned at the first position when the electrical potential difference is applied between the first and second electrodes of the at least one microactuator, and (d) the difference between the electrical potential of the 10 second electrical potential state and the electrical potential of the third electrical potential state and the difference between the electrical potential of the first electrical potential state and the electrical potential of the fourth electrical potential state are voltages which 15 maintain at the first position and do not restore to the second position the movable section of at least one microactuator, among the plurality of microactuators, having the movable section positioned at the first position when the electrical potential differences are applied between the 20 first and second electrodes of the at least one microactuator.

In this case, it is desirable that the first electrical potential state and the third electrical potential state be the same.

25 An optical switch array of the present invention

comprises the second microactuator array, and mirrors disposed at the respective movable sections of the plurality of microactuators.

An optical switch system of the present invention
5 comprises the second or third microactuator device, and mirrors disposed at the respective movable sections of the plurality of microactuators.

BRIEF DESCRIPTION OF THE DRAWINGS

10

Fig. 1 is a schematic structural view of an example of an optical switch system comprising an optical switch array, in a first embodiment of the present invention.

Fig. 2 is a schematic plan view of one optical switch
15 which is a unit element in the optical switch array used in the optical switch system in the first embodiment of the present invention.

Fig. 3 is a schematic sectional view taken along line X11-X12 in Fig. 2.

20 Fig. 4 is a schematic sectional view taken along line X13-X14 in Fig. 2.

Fig. 5 is a schematic sectional view taken along line X15-X16 in Fig. 2.

25 Fig. 6 is a schematic sectional view taken along line Y11-Y12 in Fig. 2.

Fig. 7 is a schematic sectional view taken along line Y13-Y14 in Fig. 2.

Fig. 8 is a schematic sectional view taken along line Y15-Y16 in Fig. 2.

5 Fig. 9 is a schematic sectional view taken along line Y17-Y18 in Fig. 2.

Fig. 10 is a schematic plan view of the optical switch array used in the optical switch system in the first embodiment of the present invention.

10 Fig. 11 is a graph illustrating the relationship between the voltage between a fixed electrode and a movable electrode and the distance between the electrodes, in electrostatic driving.

15 Fig. 12 is an electrical circuit diagram illustrating the optical switch array used in the optical switch system in the first embodiment of the present invention.

20 Fig. 13 is a timing chart of electrical potentials which an external control circuit applies to terminals in the optical switch system in the first embodiment of the present invention.

Fig. 14 is an electrical circuit diagram illustrating an optical switch array of an optical switch system of a comparative example.

25 Fig. 15 is an electrical circuit diagram illustrating an optical switch array of an optical switch system of

another comparative example.

Fig. 16 is a timing chart of electrical potentials which an external control circuit applies to terminals in an optical switch system in a second embodiment of the present 5 invention.

Fig. 17 is an electrical circuit diagram illustrating an optical switch array of an optical switch system in a third embodiment of the present invention.

Fig. 18 is a timing chart of electrical potentials 10 which an external control circuit applies to terminals in the optical switch system in the third embodiment of the present invention.

Fig. 19 is a schematic sectional view of the main portion of an optical switch system in a fourth embodiment 15 of the present invention, with a mirror being held at an upper side.

Fig. 20 is a schematic sectional view of the main portion of the optical switch system in the fourth embodiment of the present invention, with the mirror being 20 held at a lower side.

Fig. 21 is a schematic perspective view of a portion of an optical waveguide substrate in Figs. 19 and 20.

Fig. 22 is a schematic structural view of an optical switch system comprising an optical switch array in a fifth 25 embodiment of the present invention.

Fig. 23 is a schematic plan view of one optical switch which is a unit element in the optical switch array used in the optical switch system in the fifth embodiment of the present invention.

5 Fig. 24 is a schematic sectional view taken along line X31-X32 in Fig. 23.

Fig. 25 is a schematic sectional view taken along line X33-X34 in Fig. 23.

10 Fig. 26 is a schematic sectional view taken along line X35-X36 in Fig. 23.

Fig. 27 is a schematic sectional view taken along line Y31-Y32 in Fig. 23.

Fig. 28 is a schematic sectional view taken along line Y33-Y34 in Fig. 23.

15 Fig. 29 is a schematic sectional view taken along line Y35-Y36 in Fig. 23.

Fig. 30 is a schematic sectional view taken along line Y37-Y38 in Fig. 23.

20 Fig. 31 is an electrical circuit diagram illustrating the optical switch array used in the fifth embodiment of the present invention.

Fig. 32 is a timing chart of electrical potentials which an external control circuit applies to terminals and of currents which are passed through coils through terminals, 25 in the optical switch system in the fifth embodiment of the

present invention.

Fig. 33 is a timing chart of electrical potentials which an external control circuit applies to terminals and of currents which are passed through coils through terminals, 5 in an optical switch system in a sixth embodiment of the present invention.

Fig. 34 is an electrical circuit diagram illustrating an optical switch array used in an optical switch system in a seventh embodiment of the present invention.

10 Fig. 35 is a timing chart of electrical potentials which an external control circuit applies to terminals and of currents which are passed through coils through terminals, in the optical switch system in the seventh embodiment of the present invention.

15 Fig. 36 is a timing chart of electrical potentials which an external control circuit 6 applies to terminals and of currents which are passed through coils through terminals, in an optical switch system in an eighth embodiment of the present invention.

20

DESCRIPTION OF PREFERRED EMBODIMENTS

Hereunder, a microactuator array of the present invention, and a microactuator device, an optical switch array, and an optical switch system, which use the 25

microactuator array, will be described with reference to the drawings.

[First Embodiment]

Fig. 1 is a schematic structural view of an example of an optical switch system comprising an optical switch array 1 in a first embodiment of the present invention. For convenience of explanation, an X axis, a Y axis, and a Z axis, which are perpendicular to each other, are defined as shown in Fig. 1 (and in the following figures). A surface 5 of a substrate 121 of the optical switch array 1 is parallel to an XY plane. The direction of an arrow among directions of the Z axis is called a +Z direction or a +Z side, whereas the opposite direction is called a -Z direction or a -Z side. A surface 10 of a substrate 121 of the optical switch array 1 is parallel to an XY plane. The direction of an arrow among directions of the Z axis is called a +Z direction or a +Z side, whereas the opposite direction is called a -Z direction or a -Z side. The same things apply to directions of the X axis and 15 directions of the Y axis. The +Z side and the -Z side are sometimes called an upper side and a lower side, respectively.

As shown in Fig. 1, the optical switch system in the embodiment comprises the optical switch array 1, m optical fibers 2 for light input, m optical fibers 3 for light output, n optical fibers 4 for light output, and an external control circuit 6 serving as a controlling section. The external control circuit 6 responds to an optical path 20 switchover state command signal and supplies to the optical switch array 1 a control signal for achieving an optical 25

path switchover state indicated by the optical path switchover state command signal. In the example shown in Fig. 1, $m = 3$ and $n = 3$, but m and n may be any number, respectively.

5 As shown in Fig. 1, the optical switch array 1 comprises the substrate 121 and $m \times n$ mirrors 12 disposed on the substrate 121. The m optical fibers 2 for light input are disposed in a plane parallel to the XY plane so that incident light is guided with respect to the substrate 121
10 from one side towards the other side in a Y axis direction. The m optical fibers 3 for light output are disposed at the other side of the substrate 121 so as to oppose the respective m optical fibers 2 for light input, and in the plane parallel to the XY plane so that light traveling in
15 the Y axis direction is incident thereupon without being reflected by any mirror 12 of the optical switch array 1. The n optical fibers 4 for light output are disposed in the plane parallel to the XY plane so that light reflected in an X axis direction by any mirror 12 of the optical switch
20 array 1 is incident thereupon. The $m \times n$ mirrors 12 are disposed on the substrate 121 in a two-dimensional matrix (lattice) arrangement so that they can move towards and away from respective intersections of light-exiting paths of the m optical fibers 2 for light input and light-incident paths
25 of the m optical fibers 4 for light output by microactuators

111 (described later). In the embodiment, the orientations of the mirrors 12 are set so that the normal lines are at an angle of 45 degrees from the X axis in the plane parallel to the XY plane. Obviously, this angle may be changed as 5 required. When the angles of the mirrors 12 are to be changed, the orientations and positions of the optical fibers 4 for light output are set in accordance with these angles. Fig. 1 shows a device which performs a switching operation by intersecting light beams in a space. In order 10 to improve coupling with a light beam, a lens is sometimes inserted in one end of each fiber.

The principle of switching optical paths in the optical switch system is the same as the principle of switching optical paths in a related two-dimensional optical switch.

15 Next, the structure of one optical switch which is a unit element in the optical switch array 1 in Fig. 1 will be described with reference to Figs. 2 to 9. Fig. 2 is a schematic plan view of one optical switch (that is, one microactuator 111 and one mirror 12 which is driven thereby) 20 which is a unit element in the optical switch array used in the optical switch system in the first embodiment of the present invention. In Fig. 2, an SiN film 144 serving as a protective film formed over the entire surface of a movable section and legs is not shown, protruding bars 149 and 150, 25 which should actually be drawn with solid lines, are drawn

with broken lines, and an Al film 142 is hatched. Fig. 3 is a schematic sectional view taken along line X11-X12 in Fig. 2. Although not shown as a figure, the schematic sectional view taken along line X19-X20 in Fig. 2 is similar to Fig. 3. 5 Fig. 4 is a schematic sectional view taken along line X13-X14 in Fig. 2. Although not shown as a figure, the schematic sectional view taken along line X17-X18 in Fig. 2 is similar to Fig. 4. Fig. 5 is a schematic sectional view taken along line X15-X16 in Fig. 2. Fig. 6 is a schematic sectional view taken along line Y11-Y12 in Fig. 2. Fig. 7 10 is a schematic sectional view taken along line Y13-Y14 in Fig. 2. Fig. 8 is a schematic sectional view taken along line Y15-Y16 in Fig. 2. Fig. 9 is a schematic sectional view taken along line Y17-Y18 in Fig. 2. Although, in Figs. 15 3 to 9, beam structures 132 and 134 are shown as not being bent in a Z axis direction, when a force is not applied to the movable section, the beam structures 132 and 134 are actually bent in the +Z direction by stress of films of the beam structures 132 and 134.

20 In the embodiment, the microactuator 111 has a cantilever structure. However, as in the aforementioned Japanese Unexamined Patent Application Publication No. 2001-42233, the microactuator may have a structure supported at both sides, using a flexure.

25 The microactuator 111 used in the embodiment comprises

the substrate 121 such as a silicon substrate or a glass substrate; legs 122a and 123a; two strip-shaped beam sections 124 and 125 which primarily extend parallel to each other in an X axis direction in plan view as seen from a Z axis direction; a connecting section 126 which is disposed at an end (a free end or an end in the X axis direction) of the beam section 124 and an end (a free end or an end in the X axis direction) of the beam section 125 for mechanically connecting these ends, and which is rectangular in plan view; a connecting section 127 for mechanically connecting and reinforcing a fixed end of the beam structure 133 of the beam section 124 and a fixed end of the beam structure 135 of the beam section 125; and a fixed electrode (first electrode) 128.

15 The fixed end (-X direction end) of the beam section 124 is mechanically connected to the substrate 121 through the leg 122a having an upstanding portion from the substrate 121 through a wiring pattern 130 (not shown in Fig. 2) formed of an Al film formed on an insulating film 129, such 20 as a silicon oxide film, disposed on the substrate 121. Similarly, the fixed end (-X direction end) of the beam section 125 is mechanically connected to the substrate 121 through the leg 123a having an upstanding portion from the substrate 121 through a wiring pattern (not shown) formed of 25 Al films formed on the insulating film 129 disposed on the

substrate 121. As mentioned above, the free ends of the beam sections 124 and 125 are mechanically connected by the connecting section 126, and the fixed ends of the beam structures 132 and 134 are mechanically connected by the 5 connecting section 127. Therefore, in the embodiment, the beam sections 124 and 125 and the connecting sections 126 and 127 form a movable section having a cantilever structure as a whole. In the embodiment, the substrate 121, the fixed electrode 128, and the insulating film 129 form a fixed 10 section.

The beam section 124 comprises two beam structures 132 and 133 mechanically connected in series in an X axis direction between the fixed end and the free end of the movable section. The beam structure 132 has the shape of a 15 strip which extends in the X axis direction in plan view as seen from a Z axis direction. The beam structure 133 has the shape of a strip, and, as shown in Fig. 2, extends primarily in the X axis direction in plan view as seen from the Z axis direction and is bent in a Y axis direction at 20 the -X side position. The beam structure 132 at the fixed end side (-X side) is a plate spring section which can be flexed in the Z axis directions, whereas the beam structure 133 at the free end side (+X side) is a rigid section which 25 is substantially rigid with respect to flexing in the Z axis directions (in the direction of the substrate 121 and the

opposite direction) and in the other directions.

The beam structure 132 is a thin film of three laminated layers comprising a lower SiN film 141, an intermediate Al film 142, and an upper protective SiN film 5 144, and functions as a plate spring. The Al film 142 of the beam structure 132 is used as part of a wire to a movable electrode for electrostatic force.

The beam structure 133 is a thin film of three laminated layers comprising a lower SiN film 141, an 10 intermediate Al film 142, and an upper protective SiN film 144, which extend continuously from the beam structure 132. By the protruding bars 149 and 150, however, the beam structure 133 has rigidity mentioned above.

Although, in Fig. 3, the beam structure 132 is shown as 15 not being bent in a Z axis direction, when a drive signal is not supplied, the beam structure 132 is actually bent upwards (in a direction opposite to the substrate 121 or the +Z direction) by the stress of the films 141, 142, and 144. Such a bent state can be achieved by properly setting the 20 film deposition conditions of the films 141, 142, and 144. In contrast, the beam structure 133 is substantially not bent in a Z axis direction regardless of whether or not a drive signal is supplied, so that, by the aforementioned rigidity, the beam structure 133 is always maintained in the 25 shape of a plate without being bent by the stress of the

films 141, 142, and 144. Accordingly, the beam structure 132 and the beam structure 133 are in a bent state or an unbent state, respectively, when a force is not applied to the beam section 124.

5 In the embodiment, the leg 122a is formed by continuously extending the SiN films 141 and 144 and the Al film 142 forming the beam structure 132 as they are. The Al film 142 is electrically connected to the wiring pattern 130 through an opening formed in the SiN film 141 at the leg 10 122a. In order to make the leg 122a stronger, a protruding bar 151 having a rectangular shape in plan view as seen from a Z axis direction is formed at the top portion of the leg 122a.

15 The beam section 125 and the leg 123a have exactly the same structures as the beam section 124 and the leg 122a, respectively. The beam structures 134 and 135 of the beam section 125 correspond to the beam structures 132 and 133 of the beam section 124, respectively. A protruding bar 152 corresponding to the aforementioned protruding bar 151 is 20 formed at the top portion of the leg 123a.

25 The connecting section 127 is formed of the two SiN films 141 and 144 extending continuously from the beam structures 133 and 135. The Al film 142 does not extend to the connecting section 127 from the beam structures 133 and 135. Therefore, the connecting section 127 is not

electrically connected at all.

In the embodiment, in order to impart rigidity to the beam structures 133 and 135 and the connecting sections 126 and 127 all together, as shown by the broken lines in Fig. 2, 5 the protruding bar 149 is formed around the outer periphery of an area including these structures and sections in plan view, and the protruding bar 150 is formed along the inner periphery of the area including these structures and sections. By the protruding bars 149 and 150, the beam 10 structures 133 and 135 are reinforced and made rigid. The beam structures 133 and 135 are substantially not bent in a Z axis direction regardless of whether or not a drive signal is supplied, so that, by the aforementioned rigidity, the beam structures 133 and 135 are always maintained in the 15 shape of a plate without being bent by the stress of the films 141, 142, and 144.

The connecting section 126 is formed by continuously extending the SiN films 141 and 144 and the Al film 142 forming the beam structures 133 and 135 as they are. A 20 mirror 12 serving as a member to be driven and formed of a metal such as Au or Ni is disposed at the connecting section 126.

The portion of the Al film 142 at the connecting section 126 is also used as a movable electrode (second 25 electrode) for electrostatic force. The fixed electrode 128

for electrostatic force, which is formed of an Al film, is disposed on an area of the substrate 121 opposing the movable electrode. Although not shown, the Al film of the fixed electrode 128 extends as a wiring pattern. By using 5 this wiring pattern along with the wiring pattern 130, a voltage (for electrostatic force) can be applied between the fixed electrode 128 and the Al film 142 of the connecting section 126 serving as a movable electrode.

As can be understood from the foregoing description, in 10 the embodiment, the movable section comprising the beam sections 124 and 125 and the connecting sections 126 and 127 is such as to be movable vertically (in the Z axis directions) with respect to the fixed section comprising the substrate 121, the fixed electrode 128, and the insulating film 129. More specifically, in the embodiment, the movable section is movable between an upper position to which the movable section tries to return by springiness of the beam structures 132 and 134 of the plate springs and a lower 15 position where the connecting section 126 comes into contact with the fixed electrode 128. At the upper position, the distance between the movable electrode (portion of the Al film 142 at the connecting section 126) of the movable section and the fixed electrode 128 of the fixed section is increased, thereby reducing or eliminating the electrostatic 20 force generated between the electrodes. At the lower 25 force generated between the electrodes. At the lower

position, the distance between the movable electrode (portion of the Al film 142 at the connecting section 126) of the movable section and the fixed electrode 128 of the fixed section is reduced, thereby increasing the 5 electrostatic force generated between the electrodes. When the voltage between both electrodes is sufficiently small, the movable section returns to the upper position by the aforementioned springiness. Accordingly, in the description below, the upper position is sometimes called an unclamp 10 position. In contrast, when the voltage between both electrodes is sufficiently large, the movable section is clamped at the lower position by the electrostatic force opposing the aforementioned springiness. Accordingly, in the description below, the lower position is sometimes 15 called a clamp position.

One end of each of the beam sections 124 and 125 is fixed at the fixed electrode, whereas the other end of each of the beam sections 124 and 125 is movable relative to the fixed electrode. When the voltage between both electrodes 20 is sufficiently large, the movable electrode moves so as to be attracted to the fixed electrode.

Here, the relationship between the voltage between both electrodes and the distance between both electrodes (this distance represents the position of the movable section) in 25 the above-described one microactuator 111 is illustrated in

Fig. 11. When the voltage between the electrodes is 0 V, the movable section is at the unclamp position. When the voltage between the electrodes gradually increases from 0 V and becomes equal to a clamp voltage V_c , the electrostatic 5 force becomes larger than the springiness, so that the movable electrode is attracted to the fixed electrode, as a result of which the movable section is moved to the clamp position. A further increase in the voltage does not change the position of the movable section. Next, even if, from 10 this value, the voltage between the electrodes is gradually reduced to a value equal to or less than the clamp voltage V_c , the movable section is not immediately unclamped. When the voltage between the electrodes reaches an unclamp voltage V_r , which is less than the clamp voltage V_c , the 15 springiness becomes greater than the electrostatic force, so that the movable section is unclamped and returned to its unclamp position. Accordingly, there is hysteresis between the distance and voltage between the electrodes. The hysteresis results from the electrostatic force varying 20 depending upon the electrode positions because the electrostatic force is inversely proportional to the square of the distance between the electrodes. Hysteresis is exhibited not only in microactuators having the above-described structure, but also generally in microactuators 25 making use of electrostatic force.

Therefore, in the embodiment, by controlling the voltage between the electrodes, it is possible to hold the mirror 12 at an upper side (side opposite to the substrate 121) and at a lower side (side of the substrate 121). In 5 the embodiment, as described later, such a controlling operation is carried out.

In the embodiment, as shown in Fig. 10, a plurality of optical switches each comprising a mirror 12 and a microactuator 111 for driving the mirror 12 are two-dimensionally disposed in a matrix on the substrate 121, and form an optical switch array. In the embodiment, as shown 10 in Fig. 2, the beam structures 133 and 135 are bent in the Y axis directions at the -X side position in plan view as seen from a Z axis direction. By this, since the beam sections 124 and 125 are bent in the Y axis directions, when, as 15 shown in Fig. 10, the plurality of microactuators 111 are two-dimensionally disposed on the substrate 121, they can be disposed closer together. In other words, since the beam sections 124 and 125 are two-dimensionally bent, a portion 20 of the beam section 124 and a portion of the beam section 125 of one microactuator are two-dimensionally superimposed on the beam sections 124 and 125 of an adjacent microactuator. That is, in Fig. 10, the beam structures 132 25 and 134 of an upper microactuator 111 are vertically superimposed on the beam structures 133 and 135 of a lower

microactuator 111. Fig. 10 is a schematic plan view of the optical switch array in the optical switch system in the embodiment.

In the embodiment, although the SiN films 144 serving 5 as protective films are formed over the entire surface of the movable section and the legs of each microactuator 111, the SiN films 144 do not have to be formed.

Fig. 12 is an electrical circuit diagram illustrating the optical switch array used in the embodiment. The single 10 optical switch shown in Figs. 2 to 9 may be regarded as one capacitor (corresponding to a capacitor comprising the fixed electrode 128 and the movable electrode (portion of the Al film 142 at the connecting section 126)) in terms of an electrical circuit. In Fig. 12, a capacitor (optical 15 switch) of an m row and n column is represented as C_{mn} . For example, the upper left capacitor (optical switch) (in the first row and first column) in Fig. 12 is represented as C_{11} . In the embodiment, the left electrode and right electrode in Fig. 12 of each capacitor are a fixed electrode and a 20 movable electrode, respectively. Obviously, for any number of capacitors equal to or greater than one, the electrical connection relationship between the fixed electrode and the movable electrode can obviously be reversed.

In Fig. 12, for convenience of explanation, nine 25 optical switches are disposed in three rows and three

columns. The number of optical switches is not limited in any way. Accordingly, when, for example, optical switches are disposed in 100 rows and 100 columns, the principle is the same. For the same number of optical switches, the 5 number of rows and columns do not have to be the same, or they do not have to be disposed in a matrix. For example, if there are nine optical switches, they may be disposed in one row and nine columns, or, if there are 16 optical switches, they may be disposed in four rows and four columns, 10 1 row and 16 columns, or two rows and eight columns.

As shown in Fig. 12, the optical switch array used in the embodiment comprises a first terminal group comprising a plurality of terminals CD1 to CD3 and a second terminal group comprising a plurality of terminals CU1 to CU3. These 15 terminals CD1 to CD3 and CU1 to CU3 are external connection terminals for connection to the external control circuit 6 shown in Fig. 1. In the embodiment, the wiring pattern 130 below the aforementioned leg 122a of each optical switch and the wiring pattern (not shown) below the leg 123a of each 20 optical switch are used to achieve the electrical connection shown in Fig. 12. The terminals CD1 to CD3 and the terminals CU1 to CU3 may be formed by, for example, using part of these wiring patterns as electrode pads. Although 25 the wiring pattern 130 below the legs 122a and the wiring pattern below the leg 123a are used in each optical switch,

only one of them need to be used.

In Fig. 12, the number of terminals CD1 to CD3 of the first terminal group is three, which is the same as the number of rows of the optical switches, and the number of 5 terminals CU1 to CU3 of the second terminal group is also three, which is the same as the number of columns of the optical switches. The number of terminals of the first and second terminal groups do not necessarily have to be the same as the number of rows and columns of the optical 10 switches, respectively, as long as, for example, the following Conditions (a) to (e) are satisfied: (a) the fixed electrode 128 of each microactuator 111 is electrically connected to one terminal of either one of the first and second terminal groups and is not electrically 15 connected to the rest of terminals of the first and second terminal groups, (b) the movable electrode of each microactuator 111 is electrically connected to one terminal of either of the other of the first and second terminal groups and is not electrically connected to the rest of the 20 terminals of the first and second terminal groups, (c) a combination of the one terminal of either the first or second terminal group electrically connected to the fixed electrode 128 in each microactuator 111 and the one terminal of either the first or second terminal group electrically 25 connected to the movable electrode in each microactuator 111

is characteristic of each microactuator 111, (d) at least one terminal of the first terminal group is electrically connected in common to the fixed electrodes 128 or the movable electrodes of two or more of the microactuators 111 in the optical switch array, and (e) at least one terminal of the second terminal group is electrically connected in common to the fixed electrodes 128 or movable electrodes of two or more of the microactuators 111 in the optical switch array.

10 The electrical connections under Conditions (a) to (e) refer to connection in terms of DC voltage. Therefore, the fixed electrode and the movable electrode of each capacitor are separated in terms of DC voltage.

15 In the example shown in Fig. 12, which satisfies the Conditions (a) to (e), the fixed electrodes 128 of the capacitors C11, C12, and C13 in the first row are electrically connected in common to the terminal CD1 of the first terminal group, and are not electrically connected to the rest of the terminals. The fixed electrodes 128 of the 20 capacitors C21, C22, and C23 in the second row are electrically connected in common to the terminal CD2 of the first terminal group, and are not electrically connected to the rest of the terminals. The fixed electrodes 128 of the capacitors C31, C32, and C33 in the third row are 25 electrically connected in common to the terminal CD3 of the

first terminal group, and are not electrically connected to the rest of the terminals. The movable electrodes of the capacitors C11, C21, and C31 in the first column are electrically connected in common to the terminal CU1 of the 5 second terminal group, and are not electrically connected to the rest of the terminals. The movable electrodes of the capacitors C12, C22, and C32 in the second column are electrically connected in common to the terminal CU2 of the second terminal group, and are not electrically connected to the rest of the terminals. The movable electrodes of the 10 capacitors C13, C23, and C33 in the third column are electrically connected in common to the terminal CU3 of the second terminal group, and are not electrically connected to the rest of the terminals.

15 As shown in Fig. 12, an address circuit, a column selecting switch, a row selecting switch, etc., are not disposed in the optical switch array used in the embodiment.

The optical switch array used in the embodiment may be manufactured by making use of technologies for manufacturing 20 semiconductors, such as a film forming technology and patterning, etching, and a sacrificial layer forming/removing technology. The mirrors 12 are formed by a method disclosed in, for example, the aforementioned Japanese Unexamined Patent Application Publication No. 2001-25 42233. In the method, recesses corresponding to the mirrors

12 are formed in a resist. Then, a metal 38, such as Au or Ni, used to form the mirrors 12 by electrolytic plating is grown, after which the resist is removed, thereby forming the mirrors 12.

5 In the embodiment, the external control circuit 6 in Fig. 1 is connected to the terminals CD1 to CD3 and to the terminals CU1 to CU3 in order to separately control the electrical potentials of these terminals, thereby controlling the optical path switchover state of each 10 optical switch of the optical switch array. The external control circuit 6 responds to an optical path switchover state command signal and supplies as an electrical potential a control signal for achieving an optical path switchover state indicated by the optical path switchover state command 15 signal to each of the terminals CD1 to CD3 and CU1 to CU3. The external control circuit 6 selectively supplies an electrical potential to each of the terminals CD1 to CD3 and CU1 to CU3. In the embodiment, as described below, the external control circuit 6 controls the electrical 20 potentials applied to the respective terminals CD1 to CD3 and CU1 to CU3 while properly making use of the hysteresis illustrated in Fig. 11 which each microactuator 111 possesses in order to control the electrical potential between both electrodes of each microactuator 111, thereby 25 achieving each optical path switchover state. Details of a

circuit structure, itself, of the external control circuit 6
are apparent from the operation example described below.

Fig. 13 illustrates an example of a timing chart of
electrical potentials that the external control circuit 6
5 applies to the terminals CD1 to CD3 and CU1 to CU3. In the
example shown in Fig. 13, the external control circuit 6
applies any one of three electrical potentials V_h , V_m , and 0
to the terminals CD1 to CD3 of the first terminal group, and
applies any one of three electrical potentials $-V_h$, $-V_m$, and
10 0 to the terminals CU1 to CU3 of the second terminal group.
Here, V_h and V_m are positive values with 0 as a reference
value, and V_h is greater than V_m . It goes without saying
that, if the relationship between the absolute values of the
electrical potentials are not changed, they may be set with
15 reference to any electrical potential level.

In the example shown in Fig. 13, prior to a time t_1 ,
the electrical potentials of the terminals CD1 to CD3 and
CU1 to CU3 are 0. By this, the voltages between the
electrodes of all nine actuators 111 are 0 V, so that all
20 actuators 111 are in an unclamp state (in which the movable
sections are at the unclamp positions (upper positions)).

At the time t_1 , the electrical potentials of the
terminals CD1 to CD3 are increased to V_h , whereas the
electrical potentials of the terminals CU1 to CU3 are
25 reduced to $-V_h$. By this, the voltages (electrical potential

differences) between the electrodes of all nine actuators 111 become equal to $2 \times V_h$. Here, each V_h is set so that $2 \times V_h$ is greater than the clamp voltage V_c shown in Fig. 11. For example, if the clamp voltage V_c is 15 V, each V_h is set 5 at 8 V. By this, the voltages between the electrodes of all nine actuators 111 are equal to or greater than the clamp voltage V_c , so that all of the actuators 111 are clamped (in which their movable sections are at the clamp positions (lower positions)).

10 At a time t_2 , the electrical potentials of the terminals CD1 to CD3 are reduced to V_m , whereas the electrical potentials of the terminals CU1 to CU3 are increased to $-V_m$. By this, the voltages between the electrodes of all nine actuators 111 become equal to $2 \times V_m$.
15 Here, each V_m is set so that it is greater than the unclamp voltage V_r shown in Fig. 11 and so that $2 \times V_m$ is less than the clamp voltage V_c . For example, if the unclamp voltage V_r is 5 V and the clamp voltage V_c is 15 V, each V_m is set at 6 V. By this, the voltages equal to $2 \times V_m$ between the 20 electrodes of all nine actuators 111 are equal to or greater than the unclamp voltage V_r , so that all of the actuators 111 remain in a clamp state.

At a time t_3 , the electrical potential of the terminal CD1 is reduced to 0, and the electrical potential of the 25 terminal CU1 is increased to 0. By this, the voltage

between the electrodes of the actuator 111, among the nine actuators 111, of the capacitor C11 becomes 0. Therefore, the voltage between the electrodes becomes equal to or less than the unclamp voltage, so that the actuator 111 of the 5 capacitor C11 is unclamped. In contrast, although the voltages between the electrodes of the capacitors C12, C13, C21, and C31 are reduced to V_m , the voltages V_m are greater than the unclamp voltage V_r . Therefore, the microactuators 111 of the capacitors C12, C13, C21, and C31 remain clamped. 10 The voltages between the electrodes of the capacitors C22, C23, C32, and C33 are kept equal to $2 \times V_m$, so that the actuators 111 of the capacitors C22, C23, C32, and C33 remain clamped.

At a time t_4 , the electrical potential of the terminal 15 CD1 is increased to V_m , and the electrical potential of the terminal CU1 is reduced to $-V_m$. By this, the voltages between the electrodes of the capacitors C11, C12, C13, C21, and C31 are increased to $2 \times V_m$. Since the voltages equal to $2 \times V_m$ between the electrodes are greater than the 20 unclamp voltage V_r and less than the clamp voltage V_c , the actuator 111 of the capacitor C11 remains unclamped, whereas the actuators 111 of the capacitors C12, C13, C21, and C31 remain clamped. Since the voltages between the electrodes of the capacitors C22, C23, C32, and C33 are kept equal to $2 \times V_m$, the actuators 111 of the capacitors C22, C23, C32, and 25

C33 remain clamped. Accordingly, at the time t_4 , none of the actuators 111 change states.

At a time t_5 , the electrical potential of the terminal CD2 is reduced to 0, and the electrical potential of the terminal CU2 is increased to 0. By this, the voltage between the electrodes of the actuator 111, among the nine actuators 111, of the capacitor C22 becomes 0. Therefore, the voltage between the electrodes becomes equal to or less than the unclamp voltage V_r , so that the actuator 111 of the capacitor C22 is unclamped. In contrast, although the voltages between the electrodes of the capacitors C12, C21, C23, and C32 are reduced to V_m , the voltages V_m are greater than the unclamp voltage V_r . Therefore, the microactuators 111 of the capacitors C12, C21, C23, and C32 remain clamped.

The voltages between the electrodes of the capacitors C11, C13, C31, and C33 are kept equal to $2 \times V_m$. Therefore, the actuator 111 of the capacitor C11 remains unclamped, and the actuators 111 of the capacitors C13, C31, and C33 remain clamped.

At a time t_6 , the electrical potential of the terminal CD2 is increased to V_m , and the electrical potential of the terminal CU2 is reduced to $-V_m$. By this, the voltages between the electrodes of the capacitors C12, C21, C22, C23, and C32 are increased to a value equal to $2 \times V_m$. Since the voltages equal to $2 \times V_m$ between the electrodes are greater

than the unclamp voltage V_r and less than the clamp voltage V_c , the actuator 111 of the capacitor C22 remains unclamped, and the actuators 111 of the capacitors C12, C21, C23, and C32 remain clamped. Since the voltages between the 5 electrodes of the capacitors C11, C13, C31, and C33 are kept equal to $2 \times V_m$, the actuator 111 of the capacitor C11 remains unclamped, and the actuators 111 of the capacitors C13, C31, and C33 remain clamped. Accordingly, at the time t_6 , none of the actuators 111 change states.

10 At a time t_7 , the electrical potential of the terminal CD3 is reduced to 0, and the electrical potential of the terminal CU3 is increased to 0. By this, the voltage between the electrodes of the actuator 111, among the nine actuators 111, of the capacitor C33 becomes 0. Therefore, 15 the voltage between the electrodes becomes equal to or less than the unclamp voltage, so that the actuator 111 of the capacitor C33 is unclamped. In contrast, although the voltages between the electrodes of the capacitors C13, C23, C31, and C32 are reduced to V_m , the V_m values are greater 20 than the unclamp voltage V_r . Therefore, the microactuators 111 of the respective capacitors C13, C23, C31, and C32 remain clamped. The voltages between the electrodes of the capacitors C11, C12, C21, and C22 are kept equal to $2 \times V_m$, so that the actuators 111 of the capacitors C11 and C22 25 remain unclamped, and the actuators 111 of the capacitors

C12 and C21 remain clamped.

At a time t_8 , the electrical potential of the terminal CD3 is increased to V_m , and the electrical potential of the terminal CU3 is reduced to $-V_m$. The voltages between the 5 electrodes of the capacitors C13, C23, C31, C32, and C33 are increased to a value equal to $2 \times V_m$. Since the voltages equal to $2 \times V_m$ between the electrodes are greater than the unclamp voltage V_r and less than the clamp voltage V_c , the actuator 111 of the capacitor C33 remains unclamped, and the 10 actuators 111 of the capacitors C13, C23, C31, and C32 remain clamped. Since the voltages between the electrodes of the capacitors C11, C12, C21, and C22 are kept equal to $2 \times V_m$, the actuators 111 of the capacitors C11 and C22 remain unclamped, and the actuators 111 of the capacitors C12 and 15 C21 remain clamped. Accordingly, at the time t_8 , none of the actuators 111 change states.

Up to now, a method of clamping all of the actuators 111 once, and, then, unclamping any of the clamped actuators 111 has been described.

20 Next, a method of clamping any particular unclamped actuator and, then, unclamping a different actuator will be described below.

At a time t_9 , the electrical potentials of the terminals CD1 and CD2 are increased to V_h , and the 25 electrical potentials of the terminals CU1 and CU2 are

reduced to $-V_h$. The voltages between the electrodes of the capacitors C_{11} and C_{22} become equal to $2 \times V_h$, that is, equal to or greater than the clamp voltage, so that the actuators 111 of the capacitors C_{11} and C_{22} are clamped
5 again. The voltages between the electrodes of the capacitors C_{12} and C_{21} become equal to $2 \times V_h$, and the voltages between the electrodes of the capacitors C_{13} , C_{23} , C_{31} , and C_{32} become equal to $V_m + V_h$. Since the voltages between these electrodes are greater than the unclamp
10 voltage V_r , the actuators 111 of the already clamped capacitors C_{12} , C_{13} , C_{21} , C_{23} , C_{31} , and C_{32} remain clamped. Since the voltage between the electrodes of the capacitor C_{33} is kept equal to $2 \times V_m$, the actuator 111 of the capacitor C_{33} remains unclamped.

15 At a time t_{10} , the electrical potentials of the terminals CD_1 and CD_2 are reduced to V_m , and the electrical potentials of the terminals CU_1 and CU_2 are increased to $-V_m$. By this, the voltages between the electrodes of the capacitors C_{11} , C_{12} , C_{13} , C_{21} , C_{22} , C_{23} , C_{31} , and C_{32} become
20 equal to $2 \times V_m$, which values are greater than the unclamp voltage V_r . Therefore, the actuators 111 of the capacitors C_{11} , C_{12} , C_{13} , C_{21} , C_{22} , C_{23} , C_{31} , and C_{32} remain clamped. Since the voltage between the electrodes of the capacitor C_{33} is kept equal to $2 \times V_m$, the actuator 111 of the
25 capacitor C_{33} remains unclamped. Accordingly, at the time

t10, none of the actuators 111 change states.

At a time t11, the electrical potential of the terminal CD1 is reduced to 0, and the electrical potential of the terminal CU2 is increased to 0. By this, the voltage 5 between the electrodes of the capacitor C12 becomes 0.

Accordingly, since the voltage between the electrodes becomes equal to or less than the unclamp voltage V_r , the actuator 111 of the capacitor C12 is unclamped. In contrast, the voltages between the electrodes of the capacitors C11, 10 C13, C22, and C32 are reduced to V_m , which values are greater than the unclamp voltage V_r . Therefore, the microactuators 111 of the capacitors C11, C13, C22, and C32 remain clamped. The voltages between the electrodes of the capacitors C21, C23, C31, and C33 are kept equal to $2 \times V_m$, 15 so that the actuator 111 of the capacitor C33 remains unclamped, and the actuators 111 of the capacitors C21, C23, and C31 remain clamped.

At a time t12, the electrical potential of the terminal CD1 is increased to V_m , and the electrical potential of the terminal CU2 is reduced to $-V_m$. By this, the voltages 20 between the electrodes of the capacitors C11, C12, C13, C22, and C32 are increased to a value equal to $2 \times V_m$. The voltages equal to $2 \times V_m$ between the electrodes are greater than the unclamp voltage V_r and less than the clamp voltage 25 V_c , so that the actuator 111 of the capacitor C12 remains

unclamped, and the actuators 111 of the capacitors C11, C13, C22, and C32 remain clamped. Since the voltages between the electrodes of the capacitors C21, C23, C31, and C33 are kept equal to $2 \times V_m$, the actuator 111 of the capacitor 33 5 remains unclamped, and the actuators 111 of the capacitors C21, C23, and C31 remain clamped. Accordingly, at the time t_{12} , none of the actuators 111 change states.

At a time t_{13} , the electrical potential of the terminal CD2 is reduced to 0, and the electrical potential of the 10 terminal CU1 is increased to 0. By this, the voltage between the electrodes of the capacitor C21 becomes 0. Therefore, since the voltage between the electrodes becomes equal to or less than the unclamp voltage V_r , the actuator 111 of the capacitor C21 is unclamped. In contrast, the 15 voltages between the electrodes of the capacitors C11, C22, C23, and C31 are reduced to V_m , which values are greater than the unclamp voltage V_r , so that the microactuators 111 of the capacitors C11, C22, C23, and C31 remain clamped. Since the voltages between the electrodes of the capacitors 20 C12, C13, C32, and C33 are kept equal to $2 \times V_m$, the actuators 111 of the capacitors C12 and C33 remain unclamped, and the actuators 111 of the capacitors C13 and C32 remain clamped.

At a time t_{14} , the electrical potential of the terminal 25 CD2 is increased to V_m , and the electrical potential of the

terminal CU1 is reduced to $-Vm$. By this, the voltages between the electrodes of the capacitors C11, C21, C22, C23, and C31 are increased to values equal to $2 \times Vm$. Since the voltages equal to $2 \times Vm$ between the electrodes are greater than the unclamp voltage Vr and less than the clamp voltage Vc , the actuator 111 of the capacitor C21 remains unclamped, and the actuators 111 of the capacitors C11, C22, C23, and C31 remain clamped. Since the voltages between the electrodes of the capacitors C12, C13, C32, and C33 are kept equal to $2 \times Vm$, the actuators 111 of the capacitors C12 and C33 remain unclamped, and the actuators 111 of the capacitors C13 and C32 remain clamped. Accordingly, at the time $t14$, none of the actuators 111 change states.

Up to now, it has been described that, from the time any of the actuators 111 is unclamped, it is possible to clamp any particular unclamped actuator 111, and, then, unclamp a different actuator 111 without affecting the remaining actuators.

In the description up to now, it is assumed that the clamp voltages Vc and the unclamp voltages Vr of all of the actuators 111 are the same. Actually, the voltages Vc and Vr of the actuators 111 are different. In the embodiment, considering the differences, when a maximum value and a minimum value among the clamp voltages Vc of all of the actuators 111 are represented by Vc_{max} and Vc_{min} ,

respectively, and a maximum value and a minimum value among the unclamp voltages V_r are represented by $V_{r\max}$ and $V_{r\min}$, respectively, they are set so that the following Relational Expressions (1) to (4) are established.

5 $2 \times V_h > V_{c\max} \dots (1)$

$V_m > V_{r\max} \dots (2)$

$2 \times V_m < V_{c\min} \dots (3)$

$V_{r\min} > 0 \dots (4)$

Here, Comparative Examples 1 and 2 for comparison with 10 the embodiment will be described.

Fig. 14 is an electrical circuit diagram illustrating an optical switch array of an optical switch system in Comparative Example 1. In Fig. 14, the same or corresponding parts to those shown in Fig. 12 are given the 15 same reference numerals, and the same descriptions will not be repeated. As shown in Fig. 14, Comparative Example 1 differs from the first embodiment in that, in accordance with the related common electrode/individual electrode external connection method, fixed electrodes of all 20 microactuators 111 are electrically connected in common on a substrate 121 and defined as common electrodes, and a terminal COM is connected to the common electrodes; and movable electrodes of the microactuators 111 are used as individual electrodes without electrically connecting them, 25 and connected to respective terminals P11, P12, P13, P21,

P22, P23, P31, P32, and P33. Accordingly, in Comparative Example 1, an external control circuit 6 controls the electrical potentials of the terminals P11, P12, P13, P21, P22, P23, P31, P32, and P33, which are set with reference to 5 the electrical potential of the terminal COM, in order to set the voltages between the electrodes of capacitors C11, C12, C13, C21, C22, C23, C31, C32, and C33 at a predetermined voltage greater than clamp voltage V_c or at 0. Structural features of Comparative Example 1 other than 10 those mentioned above are the same as those of the first embodiment.

In both the first embodiment and Comparative Example 1, only terminals are formed at the microactuators 111 of the optical switch array, so that an address circuit, a 15 selecting switch (circuit), etc., are not formed. As can be seen from a comparison between Figs. 14 and 12, 10 external connection terminals are required in Comparative Example 1, whereas only six connection terminals are required in the embodiment, so that the number of terminals is considerably 20 reduced.

Fig. 15 is an electrical circuit diagram illustrating an optical switch array of an optical switch system in Comparative Example 2. In Fig. 15, the same or corresponding parts to those shown in Fig. 12 are given the 25 same reference numerals, and the same descriptions will not

be repeated. As shown in Fig. 15, Comparative Example 2 differs from the first embodiment in that selecting switches M11a, M11b, M12a, M12b, M13a, M13b, M21a, M21b, M22a, M22b, M23a, M23b, M31a, M31b, M32a, M32b, M33a, and M33b, and a 5 vertical decoder and a horizontal decoder are disposed on a substrate 121 in accordance with the related address circuit mounting method. The selecting switches and decoders are disposed as selecting switches and address circuits for selecting optical switches. Accordingly, in Comparative 10 Example 2, an external control circuit 6 is not used, and an optical path switchover state command signal is supplied to the vertical decoder and the horizontal decoder through terminals (not shown). In addition, terminals COM to which fixed electrodes of all microactuators 111 are connected in 15 common and a terminal Vdd for applying a source voltage between the terminals COM are mounted to the substrate 121. Structural features of Comparative Example 2 other than those mentioned above are the same as those of the first embodiment.

20 In Comparative Example 2, only a few terminals are required. However, a address circuit, a selecting switch, etc., formed using, for example, CMOS are mounted to the substrate 121, thereby, for example, (1) increasing the size of each actuator because, for example, highly pressure- 25 resistant MOS having a larger planar size than an ordinary

MOS must inevitably be used, (2) increasing costs because the number of steps of an optical switch array production process is increased by a MOS production step, and (3) increasing costs due to the addition of a smoothening step,
5 which is carried out because, if smoothening is not sufficiently carried out after producing MOS, the shape of a base is transferred to the shape of MEMS to be formed on the MOS, resulting in malfunctioning. In particular, selecting switches are required on the substrate 121. In contrast,
10 such problems do not occur in the first embodiment because an address circuit, a selecting switch, etc., are not mounted on the substrate in the optical switch array.

Accordingly, in the embodiment, the number of external connection terminals (that is, the number of wires which are
15 externally connected) can be reduced because an address circuit, a selecting switch, etc. are not mounted. In particular, it is not necessary to dispose a selecting switch circuit on the substrate 121.

[Second Embodiment]

20 Fig. 16 is a timing chart of electrical potentials which an external control circuit 6 applies to terminals CD1 to CD3 and CU1 to CU3 in an optical switch system in a second embodiment of the present invention, and corresponds to Fig. 13.

25 This embodiment only differs from the first embodiment

in that, whereas in the first embodiment, as shown in Fig. 13, the external control circuit 6 is constructed so that it applies electrical potentials that do not change with time to the terminals CD1 to CD3 and CU1 to CU3 in each period, 5 in the second embodiment, as shown in Fig. 16, an external control circuit 6 is constructed so that it applies electrical potentials which vary in the form of pulses with time to the terminals CD1 to CD3 and CU1 to CU3 in each period. The electrical potentials applied to the terminals 10 CD1 to CD3 and those applied to the terminals CU1 to CU3 have opposite phases in each period. In Fig. 16, the amplitudes of the electrical potentials applied to the terminals CD1 to CD3 and CU1 to CU3 in each period are equivalent to the absolute values of the electrical 15 potentials applied to the terminals CD1 to CD3 and CU1 to CU3 in each period in Fig. 13. Therefore, even when electrical potentials are supplied as shown in Fig. 16, the same operations as those carried out when electrical potentials are supplied as shown in Fig. 13 are achieved.

20 In addition to the advantages of the first embodiment, the second embodiment provides the advantage that it is possible to prevent charging of each actuator 111.

25 Although, in the embodiment, electrical potentials which change in the form of pulses with time are applied to the terminals CD1 to CD3 and CU1 to CU3 in each period, it

is possible to apply electrical potentials which change sinusoidally with time to the terminals CD1 to CD3 and CU1 to CU3 in each period. Even in this case, the same advantages as those of the embodiment are obtained.

5 [Third Embodiment]

Fig. 17 is an electrical circuit diagram illustrating an optical switch array of an optical switch system in a third embodiment of the present invention. Fig. 18 is a timing chart of electrical potentials which an external 10 control circuit 6 applies to terminals CD1 to CD3 and CU1 to CU3 in the optical switch system in the third embodiment of the present invention, and corresponds to Fig. 13.

This embodiment only differs from the first embodiment in electrical connection relationships between 15 microactuators 111 and the terminals CD1 to CD3 and CU1 to CU3 on a substrate 121 of the optical system array, and states of application of electrical potentials to the terminals CD1 to CD3 and CU1 to CU3 by the external control circuit 6.

20 In this embodiment, fixed electrodes 128 of capacitors C11, C23, and C32 are connected in common to the terminal CD1, fixed electrodes 128 of capacitors C21, C12, and C33 are connected in common to the terminal CD2, and fixed 25 electrodes 128 of capacitors C31, C22, and C13 are connected in common to the terminal CD3. Movable electrodes of the

capacitors C13, C21, and C32 are connected in common to the terminal CU1, movable electrodes of the capacitors C23, C12, and C31 are connected in common to the terminal CU2, and movable electrodes of the capacitors C33, C22, and C11 are 5 connected in common to the terminal CU3. Even if the capacitors and terminals are electrically connected in such relationships, the Conditions (a) to (e) given in the first embodiment are satisfied.

In the embodiment, since the capacitors and terminals 10 are electrically connected in such relationships, the external control circuit 6 is constructed so as to apply electrical potentials to the terminals CD1 to CD3 and CU1 to CU3 as shown in Fig. 18. Fig. 18 shows an example of a timing chart for achieving the same operations as those 15 achieved based on Fig. 13 in each period.

This embodiment provides the same advantages as those of the first embodiment. In the present invention, the third embodiment may be modified in the same way as the first embodiment is modified to achieve the second 20 embodiment.

[Fourth Embodiment]

Figs. 19 and 20 are each schematic sectional views of the main portion of an optical switch system in a fourth embodiment of the present invention. Fig. 19 shows a state 25 in which a mirror 12 is held at an upper side and moved in

an optical path. Fig. 20 shows a state in which the mirror 12 is held at a lower side and moved away from the optical path. In Figs. 19 and 20, the structure of a microactuator 111 is shown considerably simplified. Fig. 21 is a 5 schematic perspective view of a portion of an optical waveguide substrate 190 in Figs. 19 and 20.

This embodiment differs from the first embodiment only in that the optical waveguide substrate 190 is disposed as shown in Figs. 19 and 20.

10 In the embodiment, as shown in Fig. 21, the optical waveguide substrate 190 has four optical waveguides 191 to 194 for transmitting light and to be switched. The optical waveguide substrate 190 has a groove 196 having a width of, for example, about tens of micrometers in the central 15 portion, with end surfaces 191a, 192a, 193b, and 194b of the respective optical waveguides 191 to 194 being exposed at side surfaces defining the groove 196. As shown in Figs. 19 and 20, the distance between the end surfaces 191a and 192a and the distance between the end surfaces 193b and 194b are 20 set so that they can be covered by a reflective surface of the mirror 12.

As shown in Figs. 19 and 20, the optical waveguide substrate 190 is disposed above a substrate 121 of the microactuator 111 and a refractive index matching liquid 202 25 is sealed in a space between the waveguide substrate 190 and

the substrate 121 and a space in the groove 196 which communicates with the space between the waveguide substrate 190 and the substrate 121. It stands to reason that, although it is not necessary to seal in the refractive index 5 matching liquid 202, light beam loss is smaller when the refractive index matching liquid is used. The substrate 121 and the optical waveguide substrate 190 are aligned so as to allow insertion of the mirror 12 into the groove 196.

Although, in Figs. 19 to 21, the optical waveguides in 10 the optical waveguide substrate 190 are shown as intersecting at one point, the optical waveguides in the optical waveguide substrate 190 are formed two-dimensionally in a matrix, so that intersection points of the optical waveguides are disposed two-dimensionally in a matrix. In 15 accordance with this, a plurality of the microactuators 111 are two-dimensionally disposed on the substrate 121, so that mirrors 12 at the respective intersection points of the optical waveguides are constructed so as to be driven by their respective microactuators 111.

20 By the aforementioned controlling operation, when, as shown in Fig. 20, the mirror 12 is disposed below the end surfaces 193b and 194b of the respective optical waveguides 193 and 194, and when, for example, light is incident upon the optical waveguide 193 from the end surface 193a, the 25 light propagates through the optical waveguide 193, exits

from the end surface 193b, impinges upon the opposing end surface 192a of the optical waveguide 192 as it is, propagates through the optical waveguide 192, and exits from the end surface 192b. If, for example, light is incident 5 upon the optical waveguide 191 from the end surface 191b, the light propagates through the optical waveguide 191, exists from the end surface 191a, impinges upon the opposing end surface 194b of the optical waveguide 194 as it is, propagates through the optical waveguide 194, and exits from 10 the end surface 194a.

In contrast, by the aforementioned controlling operation, when, as shown in Fig. 19, the mirror 12 is positioned so as to cover the end surfaces 193b and 194b of the respective optical waveguides 193 and 194, and, when, 15 for example, light is incident upon the optical waveguide 193 from the end surface 193a, the light propagates through the optical waveguide 193, exits from the end surface 193b, is reflected by the mirror 12, impinges upon the end surface 194b of the optical waveguide 194, propagates through the 20 optical waveguide 194, and exits from the end surface 194a.

If, for example, light is incident upon the optical waveguide 191 from the end surface 191b, the light propagates through the optical waveguide 191, exits from the end surface 191a, is reflected by the mirror 12, impinges 25 upon the end surface 192a of the optical waveguide 192,

propagates through the optical waveguide 192, and exits from the end surface 192b.

This embodiment provides the same advantages as those of the first embodiment. In the present invention, the 5 second and third embodiments may be modified as the first embodiment is modified to achieve the fourth embodiment.

[Fifth Embodiment]

Fig. 22 is a schematic structural view of an optical switch system comprising an optical switch array 201 in a 10 fifth embodiment of the present invention. In Fig. 22, the same or corresponding parts to those shown in Fig. 1 are given the same reference numerals, and the same descriptions will not be repeated.

This embodiment only differs from the first embodiment 15 in that the optical switch array 201 is used instead of the optical switch array 1; a magnet 5 is additionally used as a magnetic field generating section for generating a magnetic field at the optical switch array 201 as described later; and an external control circuit 6 operates 20 differently.

In the embodiment, as shown in Fig. 22, the magnet 5 is a plate-shaped permanent magnet having its -X side magnetized as an N pole and its +X side magnetized as an S pole, and is disposed below the optical switch array 201 in 25 order to generate a magnetic field indicated by magnetic

force lines 5a at the optical switch array 201. In other words, the magnet 5 generates a substantially uniform magnetic field towards the +X side with respect to the optical switch array 201. Obviously, instead of the magnet 5, for example, a permanent magnet with a different shape or an electromagnet may be used as the magnetic field generating section.

The optical switch array 201 only differs from the optical switch array 1 in that, instead of the optical switch shown in Figs. 2 to 9, an optical switch shown in Figs. 23 to 30 is used as an optical switch which is a unit element. The optical switch shown in Figs. 23 to 30 only differs from the optical switch shown in Figs. 2 to 9 in that a microactuator 211 is used instead of the microactuator 111.

Fig. 23 is a schematic plan view of one optical switch (that is, one microactuator 211 and one mirror 12 driven by the microactuator 211) which is a unit element in the optical switch array used in the optical switch system in the fifth embodiment of the present invention. In Fig. 23, an SiN film 144 serving as a protective film formed over the entire surface of a movable section and legs is not shown, protruding bars 149 and 150, which should actually be drawn with solid lines, are drawn with broken lines, and Al films 142 and 143 are hatched. Fig. 24 is a schematic sectional

view taken along line X31-X32 in Fig. 23. Although not drawn as a figure, the schematic sectional view taken along line X39-X40 in Fig. 23 is similar to Fig. 24. Fig. 25 is a schematic sectional view taken along line X33-X34 in Fig. 23.

5 Although not drawn as a figure, the schematic sectional view taken along line X37-X38 in Fig. 23 is similar to Fig. 25. Fig. 26 is a schematic sectional view taken along line X35-X36 in Fig. 23. Fig. 27 is a schematic sectional view taken along line Y31-Y32 in Fig. 23. Fig. 28 is a schematic

10 sectional view taken along line Y33-Y34 in Fig. 23. Fig. 29 is a schematic sectional view taken along line Y35-Y36 in Fig. 23. Fig. 30 is a schematic sectional view taken along line Y37-Y38 in Fig. 23. Although, in Figs. 24 to 30, beam structures 132 and 134 are shown as not being bent in a Z

15 axis direction, when a force is not applied to the movable section, the beam structures 132 and 134 are actually bent in the +Z direction by stress of films of the beam structures 132 and 134. In Figs. 23 to 30, the same or corresponding parts to those shown in Figs. 2 to 9 are given

20 the same reference numerals, and the same descriptions will not be repeated.

Basically, the microactuator 211 shown in Figs. 23 to 30 only differs from the microactuator 111 shown in Figs. 2 to 9 in that, whereas the microactuator 111 in the first

25 embodiment only makes use electrostatic force, the

microactuator 211 in the embodiment makes use of not only electrostatic force but also Lorentz force.

In the microactuator 211, a fixed end (-X direction end) of a beam section 124 is mechanically connected to a 5 substrate 121 through a leg 122 comprising two individual leg portions 122a and 122b having upstanding portions from the substrate 121 through respective wiring patterns 130 and 131 (not shown in Fig. 23) formed of Al films formed on an insulating film 129, such as a silicon oxide film, on the 10 substrate 121. Similarly, a fixed end (-X direction end) of a beam section 125 is mechanically connected to the substrate 121 through a leg 123 comprising two individual leg portions 123a and 123b having upstanding portions from the substrate 121 through two respective wiring patterns 15 (not shown) formed of Al films formed on the insulating film 129 on the substrate 121.

The beam structure 132 is a thin film of three laminated layers of a lower SiN film 141, intermediate Al films 142 and 143, and an upper protective SiN film 144 20 (there are two layers in a gap between the Al films 142 and 143), and functions as a plate spring. The Al films 142 and 143 are formed in the same layer, and are, as shown in Fig. 23, formed with a slight gap therebetween in a Y axis direction and electrically isolated from each other. This 25 is because the Al film 142 is used as a wire to a movable

electrode for electrostatic force, and the Al film 143 is used as a wire for forming a current path for Lorentz force. Almost no electric current flows through the wire for electrostatic force, whereas a relatively large amount of 5 current flows through the wire for Lorentz force. Therefore, in order to reduce electrical resistance of the wire for Lorentz force, the Al film 142 is formed with a small width, and the Al film 143 is formed with a large width.

The beam structure 133 is a thin film of three 10 laminated layers comprising a lower SiN film 141, intermediate Al films 142 and 143, and an upper protective SiN film 144, which extend continuously from the beam structure 132 (there are two layers in a gap between the Al films 142 and 143).

15 In the embodiment, the leg 122 is formed by continuously extending the SiN films 141 and 144 and the Al films 142 and 143 forming the beam structure 132 as they are, and comprise the two individual leg portions 122a and 122b. The leg 122 comprises the two individual leg portions 122a 20 and 122b in order to separate the wire for electrostatic force and the wire for Lorentz force and electrically connect the Al film 142 and the Al film 143 to the separate wiring patterns 130 and 131 on the substrate 121. The Al film 142 is electrically connected to the wiring pattern 130 25 through an opening formed in the SiN film 141 at the

individual leg portion 122a. The Al film 143 is electrically connected to the wiring pattern 131 through an opening formed in the SiN film 141 at the individual leg portion 122b. In order to make the leg 122 stronger, a 5 protruding rod 151 is formed with a square shape at the top portion of the leg 122 so as to surround the individual leg portions 122a and 122b in plan view as seen from a Z axis direction.

The beam section 125 and the leg 123 have exactly the 10 same structures as the above-described beam section 124 and the leg 124, respectively. The beam structure 134 and a beam structure 135 of the beam section 125 correspond to the beam structures 132 and 133 of the beam section 124, respectively. The individual leg portions 123a and 123b of 15 the leg 123 correspond to the individual leg portions 122a and 122b of the leg 122. A protruding rod 152 corresponding to the protruding rod 151 is formed at the top portion of the leg 123.

A connecting section 127 comprises the two SiN films 20 141 and 144 extending continuously from the beam structures 133 and 135. The Al films 142 and 143 do not extend to the connecting section 127 from the beam structures 133 and 135. Therefore, the connecting section 127 is not electrically connected at all.

25 A connecting section 126 is formed by continuously

extending the SiN films 141 and 144 and the Al films 142 and 143 forming the beam structures 133 and 135 as they are. A mirror 12 serving as a member to be driven and formed of a metal such as Au or Ni are disposed at the connecting
5 section 126.

As shown in Fig. 23, in the connecting section 126, the Al film 142 and the Al film 143 are separated from each other, and a portion of the Al film 142 at the connecting section 126 serves as a movable electrode for electrostatic
10 force. A fixed electrode 128 for electrostatic force, formed of an Al film, is disposed on an area of the substrate 121 opposing the movable electrode. Although not shown, the Al film of the fixed electrode 128 extends as a wiring pattern. By using this wiring pattern along with the
15 wiring pattern 130, a voltage (electrostatic voltage) can be applied between the fixed electrode 128 and the portion of the Al film 142 at the connecting section 126, serving as the movable electrode.

As can be understood from the foregoing description,
20 the Al film 143 forms an electrical current path extending as follows from the wiring pattern 131 below the individual leg portion 122b of the leg 122: the beam structure 132 → the beam structure 133 → the connecting section 126 → the beam structure 135 → the beam structure 134 → the wiring
25 pattern (not shown) below the individual leg portion 123b of

the leg 123. When a portion of the electrical current path along a Y axis direction at the connecting section 126 among the portions of the electrical current path is placed in a magnetic field extending in an X axis direction, the portion 5 is a portion for generating Lorentz force in a Z axis direction. Therefore, when the portion is placed in a magnetic field in an X axis direction using the permanent magnet 5 shown in Fig. 22, and an electrical current (for Lorentz force) is passed through the electrical current path, 10 a Lorentz force (driving force) acts in a Z direction at the portion of the Al film 143 at the connecting section 126. The direction of the Lorentz force is either in the +Z direction or the -Z direction depending upon the direction of the electrical current for Lorentz force.

15 Therefore, in the embodiment, by controlling the voltage between the electrodes and the electrical current for Lorentz force, it is possible to hold the mirrors 12 at an upper side (side opposite to the substrate 121) and at a lower side (side of the substrate 121). In the embodiment, 20 as described later, such a controlling operation is carried out.

In the embodiment, a plurality of the optical switches each comprising a mirror 12 and a microactuator 211 for driving the mirror 12 are two-dimensionally disposed in a 25 matrix on the substrate 121, and form an optical switch

array.

Fig. 31 is an electrical circuit diagram illustrating the optical switch array used in the embodiment. In Fig. 31, the same or corresponding parts to those shown in Fig. 12 5 are given the same reference numerals, and the same description will not be repeated. The single optical switch shown in Figs. 23 to 30 may be regarded as one capacitor (corresponding to a capacitor comprising the fixed electrode 128 and the movable electrode (portion of the Al film 142 at 10 the connecting section 126)) and as one coil (portion of the Al film 143 at the connecting section 126) in terms of an electrical circuit. In Fig. 31, a capacitor of an m row and an n column and a coil of an m row and an n column of an optical switch is represented as C_{mn} and L_{mn} , respectively.

15 In the embodiment, coils L_{mn} are added, so that, as shown in Fig. 31, a third terminal group comprising a plurality of terminals $L0$ to $L3$ is added. One of the ends of each of coils $L11$, $L21$, and $L31$ in the first column is electrically connected to the terminal $L1$ of the third 20 terminal group. One of the ends of each of coils $L12$, $L22$, and $L32$ in the second column is electrically connected to the terminal $L2$ of the third terminal group. One of the ends of each of coils $L13$, $L23$, and $L33$ in the third column 25 is electrically connected to the terminal $L3$ of the third terminal group. The other ends of all of the coils are

electrically connected in common to the terminal L0 of the third terminal group. In order to restrict the amount of electrical current flowing in the wiring patterns, for example, the other ends of the coils L11, L21, and L31 in 5 the first column may be electrically connected in common to one terminal, the other ends of the coils L12, L22, and L32 in the second column may be electrically connected in common to another terminal, and the other ends of the coils L13, L23, and L33 in the third column may be electrically 10 connected in common to still another terminal.

Fig. 32 is a timing chart of electrical potentials which an external control circuit 6 applies to terminals CD1 to CD3 and CU1 and CU3 and of currents which are passed through the coils through the respective terminals L1 to L3, 15 in the optical switch system in the embodiment, and corresponds to Fig. 13.

Fig. 32 shows a timing chart for achieving the same operations as those achieved based on Fig. 13 in each period. In each period, the electrical potentials applied to the 20 terminals CD1 to CD3 and CU1 to CU3 in Fig. 32 are basically the same as those in Fig. 13. However, the electrical potentials applied to the terminals CD1 to CD3 in a period t_1 to t_2 and a period t_9 to t_{10} are $V_{h'}$, which are positive values less than V_h , and the electrical potentials applied 25 to the terminals CU1 to CU3 in the period t_1 to t_2 and the

period t_9 to t_{10} are $-Vh'$. A value equal to $2 \times Vh'$ does not necessarily have to be greater than V_{cmax} . In the period t_1 to t_2 , current I_h flows through the terminals L_1 to L_3 , and, in the period t_9 to t_{10} , the current I_h flows 5 through the terminals L_1 and L_2 . The current I_h is in a direction in which a downward Lorentz force is generated (that is, a direction in which a movable section moves to a clamp position).

In the first embodiment, as shown in Fig. 13, in the 10 period t_1 to t_2 and the period t_9 to t_{10} , corresponding actuators 211 are maintained in a clamped state by electrostatic force alone after being clamped from an unclamped state. In contrast, in the embodiment, in the period t_1 to t_2 and the period t_9 to t_{10} , electrostatic 15 force and Lorentz force can both be used. Since Lorentz force does not depend upon the distance between electrodes, in the embodiment, the clamping is maintained mainly by Lorentz force when a movable electrode starts moving. When the distance between a movable electrode and a fixed 20 electrode 128 becomes smaller than a certain value, the electrostatic force is increased, thereby making it possible to maintain the clamped state by the electrostatic force alone. Therefore, at a time t_2 , even if the current is set at 0, the clamped state is maintained. In this way, when 25 Lorentz force is used, the amount of electrostatic force is

sufficient when it allows the clamped state to be maintained. Therefore, in the period t_1 to t_2 and the period t_9 to t_{10} , the voltage between the electrodes of a corresponding actuator 211 only needs to be equal to $2 \times V_{h'}$, which is 5 less than $2 \times V_h$ in Fig. 13.

This embodiment provides the same advantages as those of the first embodiment. The fifth embodiment may be modified as the first embodiment is modified to achieve the second and fourth embodiments.

10 [Sixth Embodiment]

Fig. 33 is a timing chart of electrical potentials which an external control circuit 6 applies to terminals CD1 to CD3 and CU1 to CU3 and of currents which are passed through coils through terminals L1 to L3, in an optical 15 switch system in a sixth embodiment of the present invention, and corresponds to Fig. 32.

This embodiment only differs from the fifth embodiment in that, whereas, in the fifth embodiment, as shown in Fig. 32, the external control circuit 6 applies any one of the 20 three electrical potentials $V_{h'}$, V_m , and 0 to the terminals CD1 to CD3 of the first terminal group and applies any one of the three electrical potentials $-V_{h'}$, $-V_m$, and 0 to the terminals CU1 to CU3 of the second terminal group, in this embodiment, as shown in Fig. 33, the external control 25 circuit 6 applies either of two electrical potentials V_n and

0 to the terminals CD1 to CD3 of a first terminal group and applies either of two electrical potentials $-V_n$ and 0 to the terminals CU1 to CU3 of a second terminal group. V_n is a positive value.

5 Fig. 33 shows a timing chart for achieving the same operations as those achieved based on Fig. 32 in each period. In the embodiment, when a maximum value and a minimum value among clamp voltages V_c of all of the actuators 111 are represented by V_{cmax} and V_{cmin} , respectively, and a maximum value and a minimum value among unclamp voltages V_r are represented by V_{rmax} and V_{rmin} , respectively, they are set so that the following Relational Expressions (5) and (6) are established.

10

$$V_n > V_{rmax} \dots (5)$$

15 $V_{rmin} > 0 \dots (6)$

The embodiment provides the same advantages as those of the fifth embodiment, and, since only a smaller number of different voltages are used, the advantage that the structure of the external control circuit 6 is simplified.

20 The sixth embodiment may be modified as the first embodiment is modified to achieve the second and fourth embodiments.

[Seventh Embodiment]

Fig. 34 is an electrical circuit diagram illustrating an optical switch array used in an optical switch system in 25 a seventh embodiment of the present invention. Fig. 35 is a

timing chart of electrical potentials which an external control circuit 6 applies to terminals CD1 to CD3 and CU1 to CU3 and of currents which are passed through coils through terminals L1 to L3, in the optical switch system in the 5 seventh embodiment of the present invention; and corresponds to Fig. 32. Fig. 35 shows an example of a timing chart for achieving the same operations as those achieved based on Fig. 33 in each period.

This embodiment only differs from the sixth embodiment 10 in electrical connection relationships between microactuators 111 and the terminals CD1 to CD3 and CU1 to CU3 on a substrate 121 of the optical switch array, states of application of electrical potentials to the terminals CD1 to CD3 and CU1 to CU3 by the external control circuit 6, and 15 states of application of currents to the coils via the terminals L1 to L3 by the external control circuit 6.

In the embodiment, as shown in Fig. 34, the electrical connection relationships between capacitors and the terminals CD1 to CD3 and CU1 to CU3 are the same as those in 20 Fig. 17. In the embodiment, due to the use of such an electrical connection, the external control circuit 6 is constructed so as to apply electrical potentials to the terminals CD1 to CD3 and CU1 to CU3 as shown in Fig. 35. In 25 each period, the electrical potentials applied to the terminals CD1 to CD3 and CU1 to CU3 in Fig. 32 are basically

the same as those in Fig. 13. However, in the embodiment, as in the sixth embodiment, the electrical potentials applied to the terminals CD1 to CD3 in a period t_1 to t_2 and a period t_9 to t_{10} are V_h' , which are positive values less 5 than V_h , and the electrical potentials applied to the terminals CU1 to CU3 in the period t_1 to t_2 and the period t_9 to t_{10} are $-V_h'$. A value equal to $2 \times V_h'$ does not necessarily have to be greater than V_{cmax} .

In the embodiment, as shown in Fig. 35, at a period t_3 10 to t_4 , an electrical current $-IL$ flows through the terminal L1, causing Lorentz force to act in a direction in which the distance between a movable electrode and a fixed electrode increases, thereby helping a capacitor C11 to change states from a clamped state to an unclamped state. This is 15 effective in increasing the unclamping speed. At this time, the coils L11, L21, and L31 are connected to the terminal L1, fixed electrodes of capacitors C21 and C31 are connected to the terminals CD2 and CD3, respectively, and movable electrodes of the capacitors C21 and C31 are connected to 20 the terminals CU1 and CU2, respectively. The voltages between the electrodes of the capacitors are maintained at values equal to $2 \times V_h'$. Therefore, actuators 211 of the capacitors C21 and C31 are clamped firmly, so that, even if Lorentz force is exerted, they are not unclamped.

25 Similarly, at a period t_5 to t_6 , an electrical current

-IL flows through the terminal L2, thereby producing Lorentz force which helps the capacitor C22 to change states from a clamped state to an unclamped state; and, at a period t7 to t8, an electrical current -IL flows through the terminal L3, 5 thereby producing Lorentz force which helps the capacitor C33 to change states from a clamped state to an unclamped state. These are effective in increasing the unclamping speeds.

The embodiment provides the same advantages as those of 10 the sixth embodiment. The seventh embodiment may be modified as the first embodiment is modified to achieve the second and fourth embodiments.

[Eighth Embodiment]

Fig. 36 is a timing chart of electrical potentials 15 which an external control circuit 6 applies to terminals CD1 to CD3 and CU1 to CU3 and of currents which are passed through coils through terminals L1 to L3, in an optical switch system in an eighth embodiment of the present invention.

This embodiment only differs from the seventh 20 embodiment in that, whereas, in the seventh embodiment, as shown in Fig. 35, the external control circuit 6 applies any one of the three electrical potentials Vh' , Vm , and 0 to the terminals CD1 to CD3 of the first terminal group and applies 25 any one of the three electrical potentials $-Vh'$, $-Vm$, and 0

to the terminals CU1 to CU3 of the second terminal group, in this embodiment, as shown in Fig. 36, the external control circuit 6 applies either of two electrical potentials V_n and 0 to the terminals CD1 to CD3 of a first terminal group and 5 applies either of two electrical potentials $-V_n$ and 0 to the terminals CU1 to CU3 of a second terminal group. V_n is a positive value.

Fig. 36 shows an example of a timing chart for achieving the same operations as those achieved based on Fig. 10 35 in each period. In the embodiment, when a maximum value and a minimum value among clamp voltages V_c of all of the actuators 111 are represented by V_{cmax} and V_{cmin} , respectively, and a maximum value and a minimum value among unclamp voltages V_r are represented by V_{rmax} and V_{rmin} , 15 respectively, they are set so that the Relational Expressions (5) and (6) are established.

The embodiment provides the same advantages as those of the fifth embodiment, and, since only a smaller number of different voltages are used, the advantage that the 20 structure of the external control circuit 6 is simplified. The eighth embodiment may be modified as the first embodiment is modified to achieve the second and fourth embodiments.

Although the present invention has been described with 25 reference to the above-described embodiments, the present

invention is not limited to these embodiments.

For example, although in the embodiments, the microactuator device of the present invention is applied to an optical switch system, the microactuator device of the 5 present invention is not limited in its application to an optical switch system.

As can be understood from the foregoing description, the present invention can provide a microactuator array which can reduce the number of wires which are externally 10 connected because an address circuit, a selecting switch, etc. are not mounted; and a microactuator device, an optical switch array, and an optical switch system, which use the microactuator array.

The above-described embodiments are examples, and 15 various modifications can be made without departing from the spirit and scope of the invention.